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Distribution of hydrogen and oxygen ion species in the plasmasheet

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Abstract

In this paper, using data obtained by Cluster 4 satellite from 2001 to 2012, we statistically investigate the spatial distributions of H^+ and O^+ in the magnetotail plasmasheet and their relation with geomagnetic indices. Our work outlines the existence of two regions with enhanced O^+ concentration in the tail plasmasheet, one is located in the mid-tail plasmasheet at $R > 17\ R_E$, and the other is located near the inner boundary of plasmasheet at $R < 10\ R_E$. The existence of the depletion region of O^+ between $10\ R_E < R < 17\ R_E$ indicates that the O^+ ions in the mid-tail plasmasheet, which come from polar cap, are not likely to be able to make important contribution to the formation of ring current. Both the distributions of density and temperature of O^+ ions have a dawn–dusk asymmetry. The number density of O^+ during geomagnetic active time ($Dst < -20$ nT/$AE > 200$ nT/$Kp \geqslant 3$) is much larger than that during non-storm time ($Dst > -20$ nT/$AE < 200$ nT/$Kp < 3$). This dawn–dusk asymmetry and the number density of O^+ varying with geomagnetic activity apply for both regions ($R < 10\ R_E$ and $R > 17\ R_E$) of O^+. Therefore both substorm and enhanced convection provide a large number of O^+ ions to the plasmasheet, which makes favorable condition for the growth of the ring current.

Keywords: Ion species; Plasmasheet; Geomagnetic activity

1. Introduction

It has been widely accepted that the ions in magnetospheric plasma mainly depend on the contribution of the solar wind and the Earth's ionosphere. The solar wind contributes H^+ and He^{++}, while the Earth's ionosphere contributes a significant portion of H^+, He^+ and O^+ to the inner magnetosphere and to the near-Earth plasmasheet ion population.

The solar wind plasma enters the Earth's magnetosphere through magnetic reconnection, diffusion, and other processes (e.g., Wing and Newell, 1998), which can explain the entry of magnetosheath plasma into the plasmasheet. These populations are subsequently transported by the electric and magnetic drift in the plasmasheet (e.g., Li et al., 2003; Liu et al., 2009). Consequently, the plasma characteristics in the plasmasheet depend on both the solar wind plasma conditions and the north-south component of IMF (B_z) with a time lag of several hours (Wing and Newell, 1998; Fu et al., 2012a; Cao et al., 2014). In addition, Walters, 1964 proposed a dawn–dusk asymmetry of the Earth's magnetosphere in the presence of an IMF with a Parker spiral orientation. This dawn–dusk asymmetry has been confirmed by in situ observations of the magnetosheath (e.g., Paularena et al., 2001; Walsh et al., 2012). Wing and Newell (1998) found that the temperature, pressure, and density of plasmasheet ions all exhibit dawn–dusk asymmetries. The dawn–dusk asymmetry of magnetotail plasmasheet has been further explained by the asymmetric ion supplier from ionosphere (Li et al., 2013) and the electric and magnetic drift in the magnetotail (Wing and Newell, 1998; Wang et al., 2006; Fu et al., 2011, 2013; Duan et al., 2014).

The ionospheric particles are ionized and heated by solar photoemissions and particle precipitation. A portion of

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them enters the magnetosphere through the plasmasphere to the inner boundary of plasmasheet and the inner magnetosphere (Mouikis et al., 2010; Fu et al., 2014). Another portion of ionospheric particles enter the middle and far tail through the auroral regions (Shelley et al., 1976; Horwitz and Moore, 1997), the ions fountain (Cladis et al., 1986; Chappell and Moore, 1987), and the cusp region (Kistler et al., 2010). The ionospheric ion outflow, as a supplier of plasma in the terrestrial magnetosphere, is at times a sufficient source to account for the observed magnetospheric plasma population (Chappell and Moore, 1987; Yau et al., 2012; Yu and Ridley, 2013a,b), and is closely related with solar wind conditions (Li et al., 2011). The O^+ ions supplied by the ionosphere can be a tracer of the ionospheric population in the plasmasheet during magnetospheric dynamic process (Liu et al., 2005).

The dynamics of the terrestrial ions in the magnetotail plasmasheet strongly depends on the geomagnetic activities (Wang et al., 2006; Cao et al., 2013). During magnetic storms, a large amount of ionospheric particles are injected into the tail from the ionosphere. In the magnetotail plasmasheet, a single oxygen injection can even account for over 80% of the oxygen population during storm time (Sauvaud et al., 2004). The increase of O^+ in the plasmasheet during substorm times is mainly due to a continuous injection (Lennartsson and Shelley, 1986).

Previous studies indicate that the plasmasheet ions density has a dawn–dusk asymmetry (Wang et al., 2006) and has an average ions number density of 0.7 cm^{-3}, between 0.4 and 2.0 cm^{-3} (Borovsky et al., 1997). The solar EUV radiation represented by $F_{10.7}$ index and geomagnetic activities represented by Kp index have no obvious influence on the H^+ density (Mouikis et al., 2010), but can control the level of O^+ density and consequently the O^+/H^+ density ratio. In addition, a recent study of the spatial profiles of the ions in the magnetotail plasmasheet using the data from the CIS of Cluster, suggest that H^+ and O^+ behave differently for various geomagnetic and solar activity levels (represented by the Kp and $F_{10.7}$ indices) (Maggiolo and Kistler, 2014).

In this paper we use the data from Cluster 4 satellite from 2001 to 2012, to study the distribution of the number density and temperature of the O^+ and H^+ ions in the plasmasheet between 8 and 20 R_E. In addition, we analyze the dependences of the O^+ density and the O^+/H^+ density ratio in the plasmasheet, on geomagnetic indices (Dst, AE and Kp indices).

2. Instrumentation and data

In this study, we use the plasmasheet data obtained by Cluster SC4 from February 2001 to December 2012 in the area bounded by $|Y_{GSE}| \leqslant 20\,R_E$ and $-20\,R_E \leqslant X_{GSE} \leqslant 0\,R_E$. The Cluster satellites have elliptical polar orbits with a perigee of around 4 R_E and an apogee of 19.6 R_E. The density and temperature data of O^+ and H^+ ions used

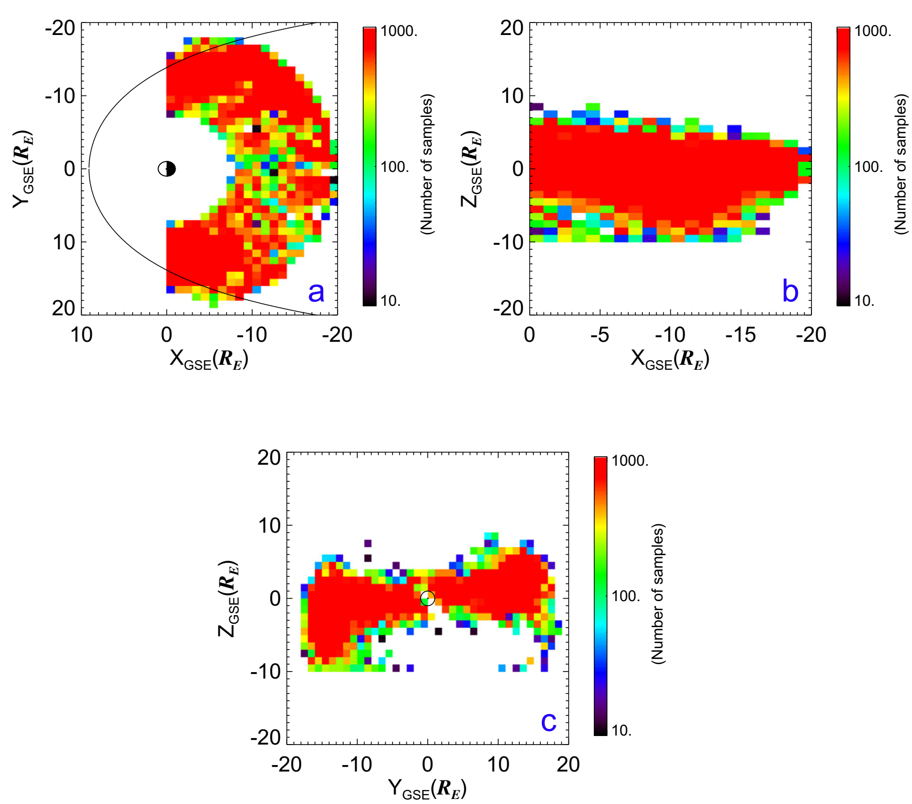

Fig. 1. Distribution of data samples in the plasmasheet in the (a) x–y plane, the (c) x–z plane, and the (e) y–z plane. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)